A Beach Probing System (BPS) for Determining Surf Zone Bathymetry, Currents, and Wave Heights from Measurements Offshore

Joan Oltman-Shay
Northwest Research Associates, Inc.
14508 NE 20th Street
Bellevue, WA 98007
Phone: (425) 644 9660 Fax: (425) 644 8422 Email: joan@nwra.com

Award #: N0001495C0217
http://www.nwra.com/bps.html

LONG-TERM GOAL

Our goal is to investigate, using both simulated and field data, the feasibility of using offshore measurements of the surface gravity wave field to remotely sense the inshore environment (hydrography, currents, and breakers).

OBJECTIVES

- To develop a data assimilation method (BPS model) for estimating the nearshore (shoreline to nominally 500m offshore) depth and alongshore-directed current profiles using offshore infragravity wave measurements. Extend the BPS model to estimate breaker type and surf zone width by assimilating wind-wave directional data.
- To develop a self-powered, self-recording, GPS-clock-accurate sensor package suite of three-axis current, pressure, and orientation sensors integrated into a semi-automated, near-real-time data acquisition, quality control, and analysis system for measurements of:
  - wind waves (0.04 - 0.35 Hz) and
  - infragravity waves (0.001 - 0.04 Hz).
- To test and evaluate the BPS model with both simulated and field (collected by the new sensor packages) data.

APPROACH

This is the end of the fourth year of a five-year program of concurrent development of the BPS model, the sensor package suite, and the data acquisition and analysis system. Field data collected at the beginning of the fourth year (Fall 1998 at Duck, NC), using the newly developed Sensor Packages, compliments simulation data in the continued development and testing of the BPS model. The Duck 1998 experiment was designed to test the capability of the BPS model for different sensor placements and environmental conditions. Two optional experiments, one to demonstrate the real-time processing and the other to investigate the ubiquity of infragravity waves on different beach genotypes, have not yet been activated.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**
4. TITLE AND SUBTITLE **A Beach Probing System (BPS) for Determining Surf Zone Bathymetry, Currents, and Wave Heights from Measurements Offshore**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Northwest Research Associates, Inc,14508 NE 20th Street,Bellevue,WA,98007**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

The basic premise of the BPS modeling and data assimilation approach is as follows:

- Acquire data from an in-situ phase array of five to seven Sensor Packages offshore of the surf zone to directly measure the wind wave and infragravity wave directional spectra,
- Apply inverse methods, and other data assimilation techniques, to estimate inshore of the array,
  - surf zone depth profile (hydrography)
  - surf zone alongshore current profile (magnitude and direction)
- Data fusion of the wind wave and infragravity wave spectral information with further modeling provides estimates of,
  - wave breaker height and type (spilling, plunging, collapsing)
  - surf zone width.

This project is multi-faceted and, as such, requires a breadth of knowledge and experience. Key personnel on this project from NorthWest Research Associates, Inc. are: Joan Oltman-Shay (a nearshore oceanographer, field experimentalist, and data analyst), Jim Secan (an ionospheric physicist, system software developer, and inverse modeler), Frank Smith (an electronics design engineer), Skip Echert (a field experimentalist), and Uday Putrevu (a nearshore theoretician and modeler). Key personnel consulting on this project are: John Booker (a geophysicist and inverse modeler from Univ. of Washington), Ed Boss (a system software developer from Sigma Solutions), Bob Bussey (a system software developer from Eagle Harbor Software), and Michael Clifton (a field logistic expert from Scripps Inst. of Oceanography, SIO). In addition, there is an advisory panel whose members were chosen to both advise on the technical approach of the project and on directions that may better serve the Navy if this technology was to transition. The members are: Barry Blumenthal (ONR), Dan Crute (CSS), Rob Holman (OSU), James Kaihatu (NRL-SSC), Steve Payne (SPAWAR), and Ed Thornton (NPGS).

WORK COMPLETED

We have successfully completed the following tasks:

- Sensor Package design, development, and testing in preparation for the Duck, NC field experiment
- Data acquisition, quality control, and analysis system design, development (up through wavenumber-frequency spectral analysis), and testing in preparation for the Duck, NC field experiment
- Two, 5-day-long field tests at Copalis beach, Washington (north of Gray's Harbor; Aug 1997 and April 1998)
- A six-week-long field experiment at Duck, NC (Sept - Oct, 1998)
- A study on how nonplanar topography influences infragravity edge waves
- Linear and nonlinear inverse model development and testing with simulated data
- Automated analysis system software development for <u>both</u> onshore and in situ (on Sensor Package) data
- Duck 98 data quality analysis and post-calibration
- Duck 98 data analysis up through wavenumber-frequency spectra

- Identification of, and solutions for, hardware and software problems with the sensor package and acquisition system

RESULTS

Sensor Package Design and Tests (Echert et al, 1996; Oltman-Shay et al, 1998b,c):
After the Duck 98 (six-week-long) experiment, the Sensor Package is now a proven design for deployment in depths of 1 to 10m. The Sensor Package operated both autonomously and with data communication, and power to and from shore. The Sensor Package can therefore be deployed on a unsupported beach without an infrastructure of shore-based power.

The Sensor Package is a 'definite-purpose' package; it is designed to be an element in a high-resolution phase-array used to measure the wind and infragravity directional spectra. Each Sensor Package contains: a Sontek ADVO (3-component Acoustic Doppler Velocimeter), a Setra 270 pressure sensor, a Precision Navigation TCM2 compass/inclinometer, an Onset Tattletale 8 (TT8) data logger/controller, a OAK 579 10 MHz Oven-Controlled Crystal Oscillator (OCXO), a Persistor 80MB flash memory card (>30 days of data), 27 alkaline D cells (4+ days of power, extended to 1month power with external battery pack), an external port for power, communication, and synchronization with shore-base station if desired, an external port for an externally mounted sensor (e.g., temperature/conductivity sensor, altimeter, other).

As a result of our experience at Duck 98, a few minor design changes will be made (e.g., choice of cable plugs), but the total design remains essentially the same. A few enhancements are being consider. For instance, it would be advantageous to be able to download data to and from each Sensor Package using divers in place of the cabling to shore.

Data Acquisition and Analysis System Design and Tests (Secan et al, 1996,97; Oltman-Shay et al., 1998b,c):
The data acqusition and analysis system design has been partially tested at both the Copalis beach field tests and the Duck 98 field experiment. Onshore data acquisition was 100% at the Copalis field test (April 1998) and approximately 60% at Duck 98; the Sensor Package cable connectors are suspect. It should be emphasised, though, that Duck 98 data acquisition was actually 90% because of the on-package data storage.

The data analysis system can be used in both a near-real-time mode, when the deployment scenario affords a Sensor Package link to shore, or in post-analysis mode. The former was tested at both Copalis and Duck. Data were processed every 17 minutes, up through wind- and infragravity-wave directional spectra, with little or no intervention by scientists. The automated data-qualitiy system was not implemented during these tests. However, the data quality was excellent at both experiments so that the absence of automated data quality control was not a hindrance.

Copalis Beach, WA Field Test (Oltman-Shay et al., 1998a):
The April 1998 Copalis field test was designed to test a full array of Sensor Packages (seven) and the concomitant near-real-time data acquisition and analysis system. However, an experiment of opportunity also presented itself with the coordination of our field test with the Washington State Department of Ecology (Ecology) bathymetry surveys (Kaminsky et al, 1997; Ruggerio and Kaminsky, 1998; Cote et al, 1998). These surveys consisted of both dry-land surveying, using a GPS-equipped vehicle and shallow-water/surf zone surveying, using a GPS-equipped jet ski (Beach et al, 1996).

The Sensor Packages were deployed at low tide and acquired data at high tide with 2.5m of water covering the Sensor Packages. The beach is low-sloping (1:60) and dissipative; the observed wind wave field was always saturated. A longshore current in 3m depth of 30cm/sec was typically observed. Both infragravity edge waves and shear instabilities were observed in the processed data. The latter was a surprise since the depth profile from low to high tide (300m) was observed to be planar. However, a few days into the experiment, Ecology ran the offshore jet ski surveys and found the presence of a 2m-high sand bar, 800m offshore. These observations were presented at the 1998 Fall AGU (Oltman-Shay et al., 1998a).

<u>BPS Model (Putrevu and Oltman-Shay, 1998; Putrevu et al., 1998, 1999):</u>
A study on describing nonplanar-topography influence-functions on fragravity edge waves was published. An unexpected result of this study was our new appreciation of the sensitivity of higher mode edge waves to shoreline bathymetric features; even though high modes have larger cross-shore scales than lower modes, they were shown to be more sensitive to shoreline shapes, such as foreshore steepening. We have since extended this work and shown that the effects of longshore curents may also be expressed in terms of influence functions.

The principal complication with inverting the dispersion relationship to determine the underlying bathymetry and longshore currents is that the inverse problem is extremely nonlinear (even though the forward problem is quite linear). Last year's report and Fall AGU presentation (Putrevu et al, 1998) discussed the linearized version of this nonlinear inverse problem and showed that in the linearized world, it is possible to completely (and accurately) deduce the topography and longshore currents by inverting the edge wave dispersion relationship (assuming that we have perfect data).

Our efforts over the last year have concentated on two fronts: 1) moving away from the fiction of error-free data, and 2) solving the fully nonlinear inverse problem. As expected, the results show that the addition of error reduces the resolution of the inverse model. However, we also found (still in the linearized setting) that features such as foreshore steepening can be easily resolved by the inverse model for reasonable errors. Bars are more difficult to resolve once we introduce data error.

Our approach to solving the nonlinear problem is an iterative one. Briefly, the procedure is as follows: We start with an estimate of the depth profile and longshore current (typically a plane beach and zero current). We assume that the depth and longshore current consist of the assumed profiles plus small unknown corrections. We then solve for the unknown corrections, update the detpth and current and repeat the procedure.

We have completed the implementation and testing of the nonlinear model outlined above. The results are essentially similar to those of the linearized problem – features such as foreshore steepening can be easily resolved using realistic data (those that contain error); bars are more difficult to resolve. To improve our capabaility of resolving bars, we are working on ways to use data from multiple tides to invert for the depth. The basic idea is each tide is different. If the bottom does not change significantly between the tides, the data from the different tides give us different looks at the bottom topography. We should be able to use these multiple looks to improve our resolution. We have run into significant unexpected difficulties in implementing the multi-tide inverse. We think that we have overcome most of the difficulties and hope to have a completely debugged version of the multi-tide inverse model by mid-November. Once we have this model ready, we will test it with data collected during our 1998 Duck experiment.

IMPACT/APPLICATION

Sixteen Sensor Packages and two automated data acquisition, quality control, and analysis systems have been developed. This field system is designed for acquisition of wave and current data in the harsh environment of the nearshore (1m to 10m depth). The Sensor Packages can be deployed autonomously (self-powered and recording) or linked to shore. In either mode, the accurate on-board clock in each package insures synchronous data acquisition between packages and other instrumentation.

The potential application of the BPS model is broader than the long-term goal of measuring surf zone environmental conditions from measurements offshore. For instance, an unexpected application of model for scientists is the estimation of the cross-shore profile of alongshore-directed current from an alongshore-aligned array of sensors. The estimation of alongshore-current profiles can come in handy in cases where deployment of a cross-shore array of sensors is prohibitive, either due to the expense or because of logistical difficulties.

Another potential benefit of the BPS model will be its application in the study of edge wave mode mix. A fundamental question about edge wave dynamics is the relative amounts of modal energy. This knowledge is important to the predictive modeling of these waves (generation and dissipation). The BPS model lays the foundation for the type of model/data analysis that is required to answer this question.

TRANSITIONS

Because the Sensor Packages are autonomous, they are attractive tools for large-scale surf zone studies where cable to shore would be prohibitive (both cost and logistics). These instruments have been proposed for use in other nearshore field efforts.

RELATED PROJECTS

"Nearshore Wave and Current Dynamics," Joan Oltman-Shay and Uday Putrevu, ONR Coastal Dynamics

"Southwest Washington Coastal Erosion Study," George Kaminsky, Washington Department of Ecology, Coastal Monitoring and Analysis Program

REFERENCES

Beach, R.A., R.A. Holman, and J. Stanley, 1996, Measuring nearshore bathymetry on high energy beaches, *Book of Abstracts, American Geophysical Union Fall Meeting, pp. F286*.

Cote, J., R.A. Holman, P. Ruggiero, 1998, Nearshore Bathymetry within the Columbia River Littoral Cell, *AGU Fall Abstracts.*.

Kaminsky, G.M., P. Ruggiero, G. Gelfenbaum, and C. Peterson, 1997, Long term coastal evolution and regional dynamics of a U.S. Pacific Northwest littoral cell, *Coastal Dynamics '97, pp. 614-623*.

Ruggiero, P. and G.M. Kaminsky, 1998, Morphologic Length Scales of High Energy Dissipative Beaches, *AGU Fall Abstracts.*

PUBLICATIONS

Echert, D.C., J. F. Smith, J. Oltman-Shay, and J. A. Secan, 1996, BPS Hardware Documentation Vol. I. Instrument Design Specification, *NWRA-CR-96-R161*.

Oltman-Shay, J., F. Smith, J. Secan, P. Ruggiero, M. Pruis, U. Putrevu, G. Kaminksy, M. Horgon, D. Echert, A. Cookson, J. Cote, E. Boss, R. Bussey, 1998a, Infragravity-Frequency-Band Waves and Currents on a Washington Coast Beach, *AGU Fall Abstracts*.

Oltman-Shay, J., J. A. Secan, D. C. Echert, and F. Smith, 1998b, BPS Semi-Annual Report #5, *NWRA-CR-98-R187*.

Oltman-Shay, J., J. A. Secan, D. C. Echert, and F. Smith, 1998c, BPS Semi-Annual Report #4, *NWRA-CR-98-R180*.

Oltman-Shay, J., J. A. Secan, D. C. Echert, and F. Smith, 1997, BPS Semi-Annual Report #3, *NWRA-CR-98-R176*.

Oltman-Shay, J., J. A. Secan, and D. C. Echert, 1996, BPS Semi-Annual Report #1, NWRA-CR-96-R160.

Putrevu, U., J. Booker, J. Oltman-Shay, M. Pruis, and M. Horgan, 1999, Inverting edge wave measurements to deduce beach topography and longshore currents, *AGU Fall Abstracts*.

Putrevu, U., and J. Oltman-Shay, 1998, Influence functions for edge wave propagation over a nonplanar bathymetry, *Physics of Fluids*, 10, 330-332.

Putrevu, U., J. Oltman-Shay, M. Pruis, and J. Booker, 1998, Deducing Beach Topography From Edge Wave Measurements, *AGU Fall Abstracts.*.

Secan, J.A., J. Oltman-Shay, R. M. Bussey, and D.C. Echert, 1997, BPS Software Documentation, Vol. I. On-shore Software Design Specification, *NWRA-CR-96-R156/R3*.

Secan, J.A., J. F. Smith, E. F. Boss, D. C. Echert, and J. Oltman-Shay, 1996, BPS Software Documentation, Vol. II. In-situ Software Design Specification, *NWRA-CR-96-R156*.